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THE NASA SCHEDULING SYSTEM

The Techniques of Scheduling in the Apollo Program

(Part 3 of 6)

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The technical aspects of scheduling as applied to the Apollo program are explored in this section. Since all schedules involved in the program require summarization and integration to provide management visability a brief statement of the levels of schedules follows:[1]

Master schedules are maintained to represent the entire Apollo program. These schedules indicate the launch dates of all flights and serve to establish the major controlled milestones affecting all missions. Associated with them are funding charts which are keyed to the launch schedule to provide visibility of the expenditure rates in the aggregate.

Level 1 schedules cover individual flight programs. Such schedules indicate the S-IC, S-II, S-IVB, IU, CSM, and LM assigned to a particular mission. They depict the status of these components as they converge on KSC for mating and checkout. These schedules include "milestones indicating the availability of the vehicle and spacecraft, the supporting launch capability, Mission Control Center operational availability, tracking and data interfaces, etc."[2]

Level 2 schedules cover specific projects. "A development plan summarizing and integrating the total development effort and, as applicable, a master delivery schedule (is) maintained for each project established at Level 2. Although, projects at this level generally correspond to the established NASA projects, variation in structure may be required to achieve meaningful schedule information and to establish the appropriate scheduling accountability. As necessary to amplify the status of selected launches shown at Level 1 and/or to meet other critical hardware development requirements, selected detailed delivery and/or operations schedules (are) prepared showing major milestones leading to the required flight readiness

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[1] Program Scheduling and Review Handbook, Washington, D.C.: NASA OMSF Program Control, NHB 2330.1, October, 1965, pp. 14-15., pp. 9-11.

[2] Ibid., p. 9-10.

and/or launch dates. For each project, a supporting Funding Schedule (is) prepared."[3]

Level 3 schedules cover <u>primary systems</u> in the projects. They highlight the developmental efforts and culminate in the delivery of the system. Examples of such systems include the spacecraft modules and the three stages of the booster. Normally the level 3 schedules apply to a particular contractor and field center. For example, Boeing would provide the input schedule information on the first stage (S-IC) which would be monitored by a project manager at Huntsville (MSFC). Similarly the development and delivery status of a particular lunar module (LM) would be indicated by information from Grumman and monitored by a project manager at Houston (MSC).

Level 4 schedules cover the <u>subordinate systems</u> to the primary systems covered by level 3 schedules. These schedules may have input data provided by a prime contractor. In some cases the primes monitor subcontractors which are responsible for the subordinate systems. Although NASA institutional managers (Office of Manned Space Flight, Headquarters Apollo Program Office (APO), field center APO's, and project and subsystem managers) maintain an overview of schedule status at all four levels the monitoring responsibility and corrective action required to achieve milestones appears to rest with the prime contractor. If his subcontractors are falling behind it is up to the prime contractor to correct the situation.

Since NASA budgeting processes are divided into Research and Development (R&D) and Construction of Facilities (C of F) the scheduling processes are similarly divided. Levels 1, 2, 3, and 4 apply to R&D activities. Levels A and B apply to facilities. Level A schedules apply to the development or site activation of facilities required to support the program. An example is the site activation of launch complex 39. Unlike R&D schedules which usually culminate in delivery dates,

[3] <u>Ibid.</u>, p. 10.

site activation schedules culimate at the operational readiness date when the facility in question can be put into use. Level B schedules provide additional information at a subordinate level to those major activities indicated in Level A facilities schedules.

Although most of the attention given to scheduling in the Apollo program has been focused on the Saturn V booster and the CSM and LM, the scope and significance of the facilities schedules should not be overlooked. The site activation of launch complex 39 including the Vehicle Assembly Building (VAB), firing control center, launch umbilical tower (LUT), mobile service structure (MSS), crawler and crawlerways, and launch pads A and B represented one of the largest and most complex construction activities ever undertaken. This task was scheduled using PERT. The associated network covered some 40,000 activities.[4]

The technical aspects of scheduling are similar for the various levels indicated above. A major difference in approach, however, is reflected in (1) the uses of PERT and (2) the utilization of bar chart techniques such as the milestone reporting techniques utilized by NASA.

In the early years of the Apollo program PERT was used extensively by NASA and its contractors. The successful application of this technique in the Polaris program resulted in widespread application of the technique for both Department of Defense and NASA projects. In many cases it became a part of the agreement with contractors that they use PERT in their scheduling. The NASA Program Scheduling and Review Handbook emphasized this technique in the following language:

"In order to provide information with respect to program logic in support of milestone schedules, PERT networks will be prepared and maintained by field centers will prepare and maintain summary PERT network logic diagrams for all R&D projects for which they are responsible. Summary networks will:

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[4] Apollo Program Management, Vol. 4, Kennedy Space Center, Program Control Office, APO, KSD 130-12-0001, 1/15/68, p. 5-6.

1. Be constructed on the basis of available detailed contractor or in-house PERT networks. Where no detailed PERT networks exist, other available schedule data will be utilized (CPM, Line of Balance, Master Schedules, planning charts, etc.).

2. Contain, as a minimum, all milestones displayed on Levels 2 and 3 schedule charts. In addition, sufficient milestones will be added to provide adequate information as to project status and to make possible the early identification of potential problem areas."[5]

This mandate, published in October 1965 and representing earlier commitments to PERT, had a significant bearing on scheduling in the Apollo program. Yet a number of problems were associated with PERT which will be discussed in some detail at a later point.

The use of bar chart schedules, specifically milestone schedules, has had a much longer history than PERT and throughout the Apollo program played a major role in the presentation and analysis of schedule status and decision processes resulting in changes.

Milestone Scheduling

Bar chart approaches to scheduling go back to the scientific management movement after the turn of the century and particularly to the work of Gantt. "Henry L. Gantt recognized that only by means of some formal device could the scheduling problem be suitably attacked. He incorporated no risk elements in his model. If speculation or risk existed, the decision maker or planner was expected to take such factors into account in an informal way. Nevertheless, Gantt charts provided a powerful tool in comparison to anything that had existed before."[6]

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[5] Ibid., p. 11.

[6] Martin K. Starr, Production Management, Systems and Synthesis. Englewood Cliffs, N.J., Prentice-Hall, Inc., 1964, p. 409.

Gantt charts involve the display of "load and work progress as a function of time, e.g., planned load and progress by machine center, or planned versus actual progress on individual orders. Gantt charts make use of a horizontal scale marked in time units. A series of horizontal lines, each representing a controlled machine or order, is used to display control data."[7]

These charts can be used to depict scheduled and actual work as horizontal lines over a time scale in a variety of ways. For example, on "a Gantt chart for machines, the machines are listed in the left-hand column, and the orders which are scheduled on these machines are noted on the lines extended toward the right side of the chart. On Gantt charts for men, the men's names are listed in the left hand column."[8] Another version lists order numbers in the left hand column with operation sequences indicated on the time lines running toward the right side of the chart.[9]

Although the Gantt chart represented the first generally used approach to depicting a schedule it had serious deficiencies. One of these was the problem of updating the charts. If they were drawn on a display board they had to be modified at every update period. Where these updates became daily routines the board was undergoing constant revision. To minimize this problem companies developed mechanical devices to facilitate the updating. Among these devices are the Productrol board using spring-loaded strings on a pegboard and the Sched-U-Graph using colored strips of paper in celluloid holders to depict scheduled work.[10]

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[7] John F. Magee and David M. Boodman, Production Planning and Inventory Control, New York, McGraw-Hill Book Company, 1967, p. 258.

[8] Richard J. Hopeman, Production: Concepts-Analysis-Control, Columbus, Ohio, Charles E. Merrill Publishing Co., 1965, p. 338.

[9] Raymond R. Mayer, Production Management, New York, McGraw-Hill Book Company, 1968, p. 309-311.

[10] R. J. Hopeman, op. cit., p. 338. For detailed discussions of these devices, see Gordon B. Carson, ed., Production Handbook, New York, The Ronald Press Company, 1958, pp. 3.25-3.45.

Other problems also are associated with Gantt charts and their variations. Some of these have to do with the deterministic assumptions associated with this approach to charting. Assumed are knowledge of lead times to acquire necessary materials, set-up times for jobs, processing times, current work loads on machines, and the current static picture of how several orders have been sequenced in the schedule.[11] Although these assumptions may be reasonable to make in typical industrial operations where relatively standardized products are produced over a long period of time, the assumptions come assunder under the conditions associated with NASA. Lead times to acquire necessary materials are often ill defined. Indeed some materials must be developed through extensive research effort, for example, the material to be utilized for the ablative heat shield to protect the command module on re-entry.

Set-up times for jobs and processing times may be quite uncertain. In some cases the processes themselves may be so specialized that the contractor must retrain his workers to meet the high manufacturing standards of NASA. As a case in point consider the simple process of soldering connections. Discussions with project managers at RCA revealed that a special soldering school had to be established at the plant to train workers to meet NASA soldering standards. Similar conditions existed at other contractor's plants. Building a command module, lunar module, or Saturn V booster stage involves processes at the fringe of the state of the art and knowing how long a process will take is probabilistic at best.

Another assumption underlying the use of various bar charts in traditional production operations is that there will be few changes once the product enters production. Given any series of ten automobiles rolling off an assembly line, any series of ten television sets going through final checks, or any series of ten electric typewriters entering the packaging operation, there is very little difference among them required by last minute engineering changes. Even if these series of ten

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[11] Howard L. Timms, The Production Function in Business, Homewood, Illinois, Richard D. Irwin, Inc., 1966, p. 519.

were increased to several thousand units the changes would be minimal. However, as one views ten spacecraft at North American Rockwell or ten lunar modules at Grumman there is no question that each is unique and has been impacted by hundreds of engineering changes while in production. While configuration management systems have been established to control these changes from a technical perspective, the problems of developing firm schedules given these uncertainties become staggering.

Even in modern industrial applications, Gantt charts, "though often thought to be the epitome of careful planning and control, usually were finally abandoned in favor of some kind of loading system which decentralized detailed scheduling and control. The usual reasons given for abandoning Gantt-type systems were that the complicated manual methods were costly to maintain and often the information represented on the charts was either inaccurate or out of date anyway. We can add in the light of present-day knowledge of queuing networks that the old Gantt systems were also static models attempting to represent a dynamic problem, and deterministic in nature where realism demanded a stochastic model."[12]

During the late 1950's and 1960's considerable progress was made in utilizing operations research techniques in solving scheduling problems. Queuing equations were developed to study the characteristics of sequential operations with special reference to differential arrival rates and service rates. Linear programming applications were made in the logistics area, product mix problems, and allocation problems associated with the assignment of men, machines, and orders. Several of the newly developed techniques were applied with the aid of computers where simulations could be run using differently configured schedules. Many of the variables which were treated deterministically were subjected to probabilistic modifications.

Whereas the developments in scheduling technology occurred rapidly during this period, most of the effort was confined to universities. Relatively few firms

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[12] Elwood S. Buffa, Production-Inventory Systems: Planning and Control, Homewood, Illinois, Richard D. Irwin, Inc., 1968, p. 355.

were willing to risk the use of such new fangled notions. Part of the reluctance, of course, was due to the fact that old techniques did indeed work, however shakily. The new techniques were relatively untested and the risk of making major scheduling errors was simply too great. Furthermore, many managers were not convinced that mathematical proofs, however exotic, outweighed their seasoned judgement in the scheduling area.

Since simulation in the space program is widely used in mission development, training of flight crews, training of firing room personnel, and training of mission control center people it would seem natural that it would also be applied to scheduling. Further, since most project managers in the Apollo program are engineers by training, the use of operations research techniques in scheduling would appear to receive widespread acceptance. However, in many interviews with project personnel, program control people, and contractor's managers little evidence of the utilization of these techniques was found.

There seem to be several reasons for this. First, the number of changes inherent in the development of Apollo hardware so severely impacts schedule status at any point in time that the application of sophisticated mathematical techniques becomes a computational exercise at best. Second, the vastness of the scheduling process involving so many contractors and field centers precludes the detailed analysis of thousands of schedule updates daily. It seems more important to focus on major accomplishments or milestones in the program than on a vast amount of detail which could impair management visibility at the project manager and program manager level. It is conceivable that if a totally integrated scheduling system were devised and updated daily, management might very well be inundated with data. Third, the nature of variables causing schedule delays are most often technical. Problems of worker absenteeism, machine breakdowns, or material shortages which often plague industrial schedulers are of minor concern to NASA personnel responsible for schedules. The factors which have far larger impacts are engineering changes, technical problems which for the moment defy solution, and test failures. To gain useful insights into the schedule ramifications of such problems the manager must be aware of the technology involved more so than particular operations research models for solving traditional job-shop scheduling problems.

NASA Techniques of Milestone Scheduling

As an example of the NASA approach to milestone scheduling consider Figure 1.[13] This sample milestone schedule specifies the data requirements for management visibility of schedule status at a particular point in time. In the center of the chart at the top are specifications as to the level of schedule, contractor involved, project name, and schedule number. In the upper right corner information is contained concerning the date on which the original schedule was approved as well as the date and number of the last schedule change. In addition the status as of a particular date specifies the "now" time line which runs vertically on the chart to highlight those activities which are ahead of or behind schedule.

The focus on schedule changes and documentation of these changes is a relatively unique characteristic of NASA scheduling when compared to traditional industiral practice. In industry the tendency is to establish a schedule for a particular time period (week, month, quarter, year, or other manufacturing period) and hold it relatively constant measuring actual performance against it. Major changes in schedules are infrequent although minor modifications are made daily.

In NASA, due to the major uncertainties associated with the technology it is not uncommon to find major schedule revisions caused by such technical developments. Further, since a delay of a single component can delay the entire program, a capability must be built in to modify the schedule dramatically as such contingencies arise. In brief, effective scheduling in NASA requires changing the schedule as well as investigating differences between actual and planned activities. With both the plan and the actual performance in a dynamic state, scheduling becomes more difficult.

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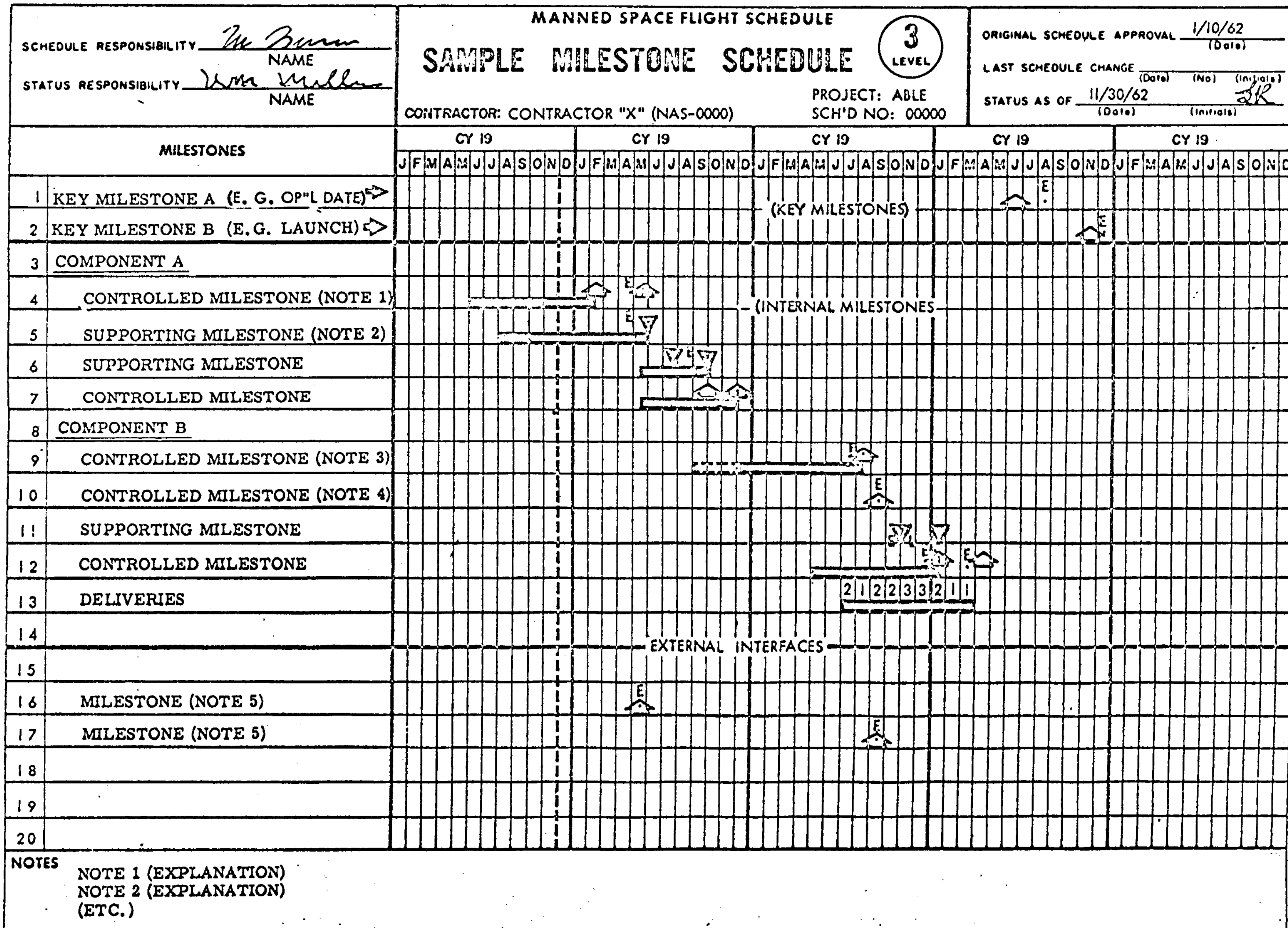
[13] Program Scheduling and Review Handbook, op. cit., p. 36.

Figure 1


MANNED SPACE FLIGHT SCHEDULE
SAMPLE MILESTONE SCHEDULE
3 LEVEL
SCHEDULE RESPONSIBILITY NAME
STATUS RESPONSIBILITY NAME
CONTRACTOR: CONTRACTOR "X" (NAS-0000)
PROJECT: ABLE
SCH'D NO: 00000
ORIGINAL SCHEDULE APPROVAL 1/10/62 (Date)
LAST SCHEDULE CHANGE (Date) (No) (Initials)
STATUS AS OF 11/30/62 (Date) (Initials)
MILESTONES
CY 19
J F M A M J J A S O N D
1 KEY MILESTONE A (E. G. OP"L DATE)
2 KEY MILESTONE B (E.G. LAUNCH)
3 COMPONENT A
4 CONTROLLED MILESTONE (NOTE 1)
5 SUPPORTING MILESTONE (NOTE 2)
6 SUPPORTING MILESTONE
7 CONTROLLED MILESTONE
8 COMPONENT B
9 CONTROLLED MILESTONE (NOTE 3)
10 CONTROLLED MILESTONE (NOTE 4)
11 SUPPORTING MILESTONE
12 CONTROLLED MILESTONE
13 DELIVERIES
14
15
16 MILESTONE (NOTE 5)
17 MILESTONE (NOTE 5)
18
19
20
(KEY MILESTONES)
(INTERNAL MILESTONES)
EXTERNAL INTERFACES
2 1 2 2 3 3 2 1 1
NOTES
NOTE 1 (EXPLANATION)
NOTE 2 (EXPLANATION)
(ETC.)

However this difficulty appears to be worth the effort. A static plan which is out of date and management attention directed toward accomplishing it is less beneficial than learning to manage with a rubber yardstick which is responsive to major changes.

Referring again to Figure 1, it will be noted that the level of detail of NASA surveillance at the headquarters level and project manager level are aggregated around major events called milestones. In the case of hardware this may involve key tests and acceptances as well as delivery to KSC. These milestones are specified as (1) key milestones, (2) controlled milestones, (3) supporting milestones, and (4) milestones involving external interfaces.

The key milestones represent major events with total program impact such as operational readiness dates of facilities like the mission control center and, of course, launch dates which pace the entire program. Controlled milestones are those deemed important enough that they can be changed only by the Office of Manned Space Flight Program Directors. Supporting milestones are of somewhat lesser importance and can be changed by the individual having schedule responsibility. This distinction implies that a project manager would have the authority to manage his project schedule in such a way that supporting milestones could be changed as necessary so long as the changes did not adversely affect a controlled milestone. External interface milestones involve those events which require interaction with other organizations which are not under the control of the person having schedule responsibility. These notations indicate where one schedule is related to another to assure that nothing "slips between the cracks."

Schedule Symbology

In the sample milestone schedule depicted in Figure 1 there are a number of horizontal bars representing the length of time a particular activity should take leading to either a controlled or supporting milestone. The open portion of the bar refers to the schedule for the future, while the blocked in portion of the bar represents work accomplished to date. By comparing the blocked in portions to the current date (indicated by a vertical line) it is possible to see at a glance those activities which are ahead of or behind schedule.

A number of special symbols are used on the milestone schedules. These symbols are summarized in Figure 2. The open arrow represents a scheduled completion date for a controlled milestone. The open inverted triangle represents the scheduled completion date for a supporting milestone. By filling in the arrow or inverted triangle one can specify the actual completion date of either a controlled or supporting milestone. If schedule revisions are required, it is possible to put numbers inside the arrow or inverted triangle. For example, in a first schedule revision, a open arrow on the bar would indicate the original schedule completion date and a new arrow with a one (1) inside of it would indicate the new scheduled completion date per the first revision. Subsequent revisions would be numbered within the arrows using sequential numbers. As pointed out earlier, the scheduled revisions for controlled milestones must be approved by the Office of Manned Space Flight Program Director. The supporting milestones, however, can be approved by those parties having schedule responsibility, such as the project manager. Where rescheduling requests are indicated on the schedule a controlled milestone arrow will appear with an x inserted into it. By scanning the chart and noting the symbols with the X's the OMSF program director can immediately pick out those milestones which are creating current problems.

Figure 2

SCHEDULE SYMBOLS

MILESTONE SYMBOLS

1.		SCHEDULED COMPLETION DATE - CONTROLLED MILESTONE
2.		SCHEDULED COMPLETION DATE - SUPPORTING MILESTONE
3.		FIRST SCHEDULE REVISION - CONTROLLED MILESTONE*
4.		FIRST SCHEDULE REVISION - SUPPORTING MILESTONE*
5.		ACTUAL COMPLETION DATE - CONTROLLED MILESTONE
6.		ACTUAL COMPLETION DATE - SUPPORTING MILESTONE
7.		RESCHEDULING REQUEST - CONTROLLED MILESTONE
8.	E •	EXPECTED COMPLETION DATE
9.	L •	LATEST ALLOWABLE COMPLETION DATE
10.	A •	PROJECT (PROGRAM) MANAGERS' ASSESSMENT OF EXPECTED COMPLETION DATE
11.	A E •	EXPECTED AND ASSESSMENT DATES IDENTICAL
12.	A EL	EXPECTED, LATEST ALLOWABLE & ASSESSMENT DATES IDENTICAL
13.		SCHEDULED AND EXPECTED DATES IDENTICAL
14.		SCHEDULED, EXPECTED AND LATEST ALLOWABLE DATES IDENTICAL (CONTROLLED MILESTONE)**
15.		SCHEDULED AND EXPECTED DATES IDENTICAL (SUPPORTING MILESTONE)
16.		SCHEDULED, EXPECTED AND LATEST ALLOWABLE DATES IDENTICAL (SUPPORTING MILESTONE)**

* Use 2 for 2nd rescheduling, 3 for 3rd rescheduling, etc.

**Shown in conjunction with a milestone rescheduled twice.

In addition to the arrow and inverted triangle symbols utilized on milestone schedule charts a number of letters are also used to provide management visibility of schedule status. The symbol E is "used to denote PERT expected completion dates of all controlled and supporting milestones as reported on contractor or in-house PERT networks. Where no PERT networks exist it will be used to indicate contractor or in-house expected completion dates derived from other scheduling techniques." The symbol L is "used to denote the latest allowable completion dates derived from PERT. The use of the L symbol is optional but if shown in a schedule chart it must always be related to the key milestone displayed on that chart." The symbol A is "used to denote a project or program manager's assessment of a milestone completion date. This symbol is required for controlled milestones when the schedule and the expected dates are not identical. The A symbol will be optional for controlled milestones when the schedule and the E dates are identical. The A symbol may be used in conjunction with supporting milestones at the discretion of the center program manager."[14]

The comparison of these symbols; arrow, inverted triangle, E, L, and A can be used in conjunction to show the variants in estimates and schedules which represent the views of those having schedule responsibility. In figure 2, items 11 through 16 represent the possible combinations of these symbols. Item 11 indicates how identical expected and assessment dates would be treated. Item 12 depicts identical expected, latest allowable and assessment dates. Item 13 represents the portrayal when scheduled and expected dates are identical. Item 14 indicates the depiction of scheduled, expected, and latest allowable dates as identical. Item 15, like item 13, indicates identical, scheduled,

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[14] Program Scheduling and Review Handbook, p. 15.

and expected dates associated with a supporting milestone rather than a controlled milestone. Finally, Item 16 shows, for a supporting milestone, identical scheduled, expected, and latest allowable dates.

Once these schedule symbols are combined with the rest of the information on a milestone schedule chart the dynamics of analysis of the chart can be undertaken. Figure 3 indicates how these symbols can be used in conjunction with activity bars to provide management visibility on actual performance against plans. Item 17, 18, and 19 depict activity initiation. In the first case, initiation is on schedule. In the second case, late initiation occurs and in the third case early initiation of the activity is predicted. Also in Figure 3, activity progress towards completion is depicted. The vertical line running through the items numbered 20 through 27 represents the current review date. Item 20 shows that the activity is on schedule, Item 21 shows it behind schedule and Item 22 shows the activity ahead of schedule. In the following activities depicted in Figure 3 numbers appear on the bar. These numbers indicate the units of hardware to be delivered. Thus, at a particular review date it is possible to count the number of items such as stages which have been delivered to KSC as of that point in time.

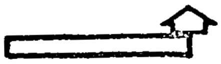
Figure 4 focuses on the charting of completion of activities or events. Items 28 through 32 illustrate the treatment of controlled milestones, and Items 33 through 39 indicate activities associated with supporting milestones. It is these areas that the letters A and E representing the expected completion date and the assessment come into play. Item 28 depicts predicted completion on schedule where the arrow and the expected completion date coincide. Item 29 has a scheduled completion date indicated by the arrow followed by an A and E symbol farther out in time. This situation reveals a predicted late completion and a project manager's assessment of completion prior to the expected

Figure 3

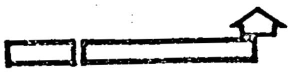
SCHEDULE SYMBOLS

USE OF SCHEDULE SYMBOLS IN CONJUNCTION WITH ACTIVITY BARS

ACTIVITY INITIATION

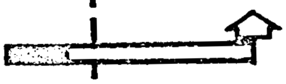
17.  PREDICTED INITIATION ON SCHEDULE

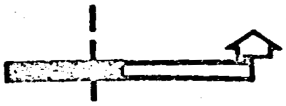
18.  PREDICTED LATE INITIATION

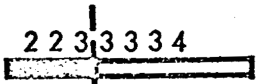
19.  PREDICTED EARLY INITIATION

ACTIVITY PROGRESS TOWARDS COMPLETION - BASIC SCHEDULE

20.  ACTIVITY ON SCHEDULE

21.  ACTIVITY BEHIND SCHEDULE

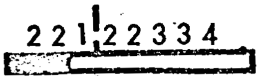
22.  ACTIVITY AHEAD OF SCHEDULE

23. 

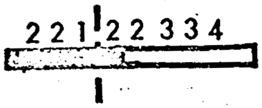
PROGRESS AGAINST SCHEDULED DELIVERIES, TEST FIRINGS, ETC. (ON SCHEDULE)

24.  LATE INITIATION - BEHIND SCHEDULE

25.  EARLY INITIATION - AHEAD OF SCHEDULE

26. 

BEHIND SCHEDULE - FOUR CUMULATIVE DELIVERIES

27. 

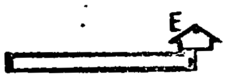
AHEAD OF SCHEDULE - SEVEN CUMULATIVE DELIVERIES

Figure 4

SCHEDULE SYMBOLS

ACTIVITY OR EVENT COMPLETION

CONTROLLED MILESTONES

28. 

PREDICTED COMPLETION ON SCHEDULE

29. 

PREDICTED LATE COMPLETION WITH PROJECT MANAGERS' ASSESSMENT

30. 

PREDICTED EARLY COMPLETION WITH PROJECT MANAGERS' ASSESSMENT

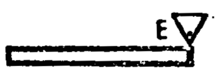
31. 

PREDICTED LATE COMPLETION WITH PROJECT MANAGERS' REQUEST FOR RESCHEDULING

32. 

RESCHEDULING REQUEST APPROVED, FIRST SCHEDULE REVISION. PREDICTED COMPLETION ON SCHEDULE

SUPPORTING MILESTONES

33. 

PREDICTED COMPLETION ON SCHEDULE

34. 

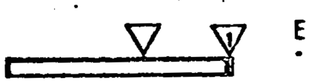
PREDICTED LATE COMPLETION (PROJECT MANAGERS' ASSESSMENT OPTIONAL)

35. 

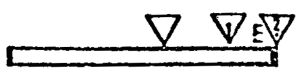
PREDICTED EARLY COMPLETION

36. 

FIRST SCHEDULE REVISION - PREDICTED COMPLETION ON SCHEDULE

37 

FIRST SCHEDULE REVISION - PREDICTED LATE COMPLETION

38. 

SECOND SCHEDULE REVISION - FIRST MONTH SUBMISSION

39. 

SECOND SCHEDULE REVISION - 2nd MONTH SUBMISSION completion date derived from PERT analysis. Item 30 is just the opposite. The scheduled completion date is the same as in Item 28 and 29, however, the PERT expected completion date is much earlier and the project manager's assessment falls between the expected completion date and the scheduled completion date. Item 31 showing the same scheduled completion date as before now has added to it a later completion expectation with the x in the arrow to indicate a project manager's request for a rescheduling of this milestone. Item 32 is a natural follow-on from Item 31. This shows the original scheduled completion date and since the x has been removed from the requested rescheduled date and replaced with a 1 it shows that the rescheduling request was approved and that this chart now has represented the first schedule revision. At this point the expected completion date and the revised schedule completion date coincide and thus the activity is predicted to be completed on schedule. The remaining items in this figure Number 33 through 39 represent similar conditions associated with supporting milestone.

The only major difference appears on Items 38 and 39. On item 38 the original scheduled completion of the supporting milestone is indicated by the open inverted triangle. The first schedule revision is shown farther out on the time line. The expected completion date is indicated by the E and a second schedule revision is indicated at the end of the time line to reflect this pessimistic expectation. In Item 39 the second schedule revision has been adopted and in the next month's summarization and submission of the schedule it will be noted that the first schedule revision is dropped out. In this manner successive schedule revisions are carried forward over time with only the original schedule and the latest submission carried showing the number of schedule revisions involved on that item in that inverted triangle.

In Figure 5 several random situations are depicted as they would show up

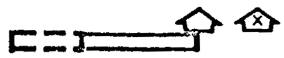
Figure 5

SCHEDULE SYMBOLS

RANDOM SITUATIONS

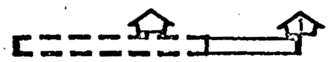
(E. and A. symbols have been omitted in portraying random situations)

LATE INITIATION & LATE COMPLETION RESCHEDULING

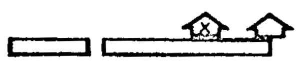
40.  CONDITION "A" - PROPOSED

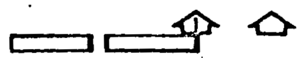
41.  CONDITION "A" - ACCEPTED

42.  CONDITION "B" - PROPOSED (RESCHEDULED INITIATION LATER THAN SCHEDULED COMPLETION)

43.  CONDITION "B" - ACCEPTED

EARLY INITIATION & EARLY COMPLETION RESCHEDULING

44.  CONDITION "C" - PROPOSED

45.  CONDITION "C" - ACCEPTED

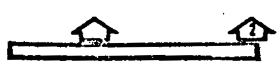
46.  CONDITION "D" - PROPOSED (RESCHEDULED COMPLETION EARLIER THAN SCHEDULED INITIATION)

47.  CONDITION "D" - ACCEPTED

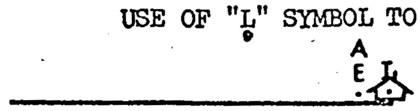
NEW COMPLETION DATE

48.  EXISTING SCHEDULE (1st RESCHEDULING)

49.  PROPOSED 2nd RESCHEDULING

50.  ACCEPTED 2nd RESCHEDULING

USE OF "L." SYMBOL TO DENOTE "LATEST ALLOWABLE COMPLETION DATE"

51. 

LATEST ALLOWABLE AND SCHEDULE DATE IDENTICAL.

PREDICTED LATE COMPLETION WITH RESPECT TO SCHEDULE DATE, BUT PREDICTED EARLY COMPLETION WITH RESPECT TO LATEST ALLOWABLE DATE.

on a milestone schedule. Items 40 through 43 reflect late initiation and late completion and the rescheduling activities associated with that. Items 44 through 47 indicate the sequence of activities involved in rescheduling early initiation and early completion. Items 48 through 50 indicate how a new completion date is scheduled when it goes through two rescheduling cycles.

In summary, the NASA approach to milestone scheduling carries forward some of the fundamental concepts of bar charts, in that activities are depicted over time against plans using horizontal lines over a time scale. As in other charts the completed portion of the work is represented by a filled in portion of the line. The uncompleted but planned work is represented by the open line projecting into the future. Also it is commonly found in industry that a vertical time line representing the review date serves to focus attention on those activities which are ahead of or behind schedule.

The distinctive features of the NASA approach rest on the utilization of controlled and supporting milestones which serve as major bench marks and also the utilization of PERT generated expected and the latest allowable completion dates. In addition, there is a possibility of incorporating the program or project manager's assessment. By comparing the expected completion dates, the latest allowable completion dates, and the more subjectively determined manager's assessment dates, it is possible to highlight those delays which are caused by technical modifications. The formal presentation of statistically derived expectations in conjunction with subjectively derived assessments is an additional feature of NASA milestone schedules not often found in industrial applications. Another unique aspect is that these charts and the associated symbology reflect a concern for modifying the schedule as new developments require that plans be changed. The provisions for schedule revisions and requests for same are apparent in the examples in Figures 2, 3, and 4.